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Improved precision of virtual height measurements with coherent radio pulse sounding based on the maximum likelihood method

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Abstract

The paper describes a new technique that improves precision of the virtual height measurements by a coherent pulse sounding of the ionosphere. Proposed technique is based on the method of maximum likelihood that matches expected and observed spectral domain signatures of the signal intermixed with the noise. Computer simulations show that our technique allows measurements of the echo virtual height with ~100 m precision even at a much coarser step of the height sampling in the sounder. In experiment, we expect an average 300 m precision of the virtual height measurements for single echoes received during periods of little spread due to ionospheric irregularities.

Keywords: Stationary-phase group delay; Maximum likelihood; Enhanced height precision; Coherent pulse sounding

1. Introduction

While vertical sounding of the ionosphere continues to be one of the most accurate technique for ionospheric specification, continuing efforts are directed at developing new ways of improving its accuracy, precision, and resolution. Existing approaches for calculation of the reflection height fall in two major categories: (1) phase difference measurements at closely spaced frequencies and (2) travel time measurements from the shape of the reflected pulse. Combination of both techniques is frequently used in the advanced ionospheric sounders (e.g., Reinisch et al., in press; Wright et al., 1980).

Precise evaluation of the virtual height from the signal travel time τ_{gr} in assumption of the propagation at the speed of light, $h' = \frac{c}{2} \cdot \tau_{gr}$, has been shown to be limited by the theoretical uncertainty bound of $\Delta h' = \frac{c}{2} \cdot \frac{1}{\alpha \cdot \Delta f \cdot \sqrt{\mu}}$ (Galkin, 1968; Barton and Ward, 1969; Skolnik, 1970), where α is the factor defined by the shape of radio pulse ($\alpha \leqslant \pi$), Δf is system frequency bandwidth, and μ is signal-to-noise ratio. For a typical μ of 6–8 and $\Delta f \sim 15$ kHz, theoretical precision of h' calculations from the group delay of the pulse is ± 0.4 km.

In the presence of ionospheric irregularities that are known to induce fading and distort the signal shape, typical uncertainty of h' measurements raises to 1–2 km or worse. Various improvements of the receiver circuitry and clever data processing techniques (e.g., calculation of the steepest slope in the echo envelope instead of the maximum or amplitude-dependent compensation of the internal system delays) are reportedly able to improve the height accuracy to 0.2 km (Wright et al., 1980).

The phase difference measurements of a virtual height at closely spaced frequencies (often referred to as the $d\phi/df$ technique or stationary-phase group height/delay) allow to receive high accuracy of about 100–200 m (Davies, 1990; Wright et al., 1980) or even 50 m (Wright and Pitteway, 1998) using the following expression

$$h' = \frac{c}{2} \cdot \frac{d\phi}{d\omega} \approx \frac{c}{2} \cdot \frac{\Delta\phi(\omega)}{\Delta\omega} = \frac{c}{2} \cdot \frac{\phi(\omega_1) - \phi(\omega_2)}{\omega_1 - \omega_2}, \tag{1}$$

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